Comments on "Preliminary Documentation for the 2007 Update of the United States National Seismic Hazard Maps"

By

Zhenming Wang

Kentucky Geological Survey
228 Mining and Mineral Resource Building
University of Kentucky
Lexington, KY 40506
zmwang@uky.edu

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The USGS hazard maps have significant implications for the nation, states, and local communities, and the updated maps should be compatible with modern earthquake science. As stated in the document, “the draft 2007 U.S. Geological Survey (USGS) National Seismic Hazard Maps display earthquake strong ground motions for varying probability levels across the United States, and are used in seismic provisions of building codes, earthquake insurance rate structures, and other public policy decisions” (p. 6). The document also states “the USGS probabilistic seismic hazard maps and the related design maps (MCE maps) are revised about every six years to ensure compatibility with new earthquake science that is either published or thoroughly reviewed, and to keep pace with regular updates of the building code” (p. 6). In fact, the document says “the goals of this update are to include the best available new science” (p. 8). Therefore, it is imperative for the USGS to fully and clearly document the methodology, input models (parameters), and products from the national seismic hazard mapping projects. It is also imperative that the methodology and input models (parameters) used for the national hazard mapping are compatible with modern earthquake science. However, we have found that the United States national seismic hazard maps, particularly their methodology (probabilistic seismic hazard analysis – PSHA) and some input models (parameters), are not compatible with modern earthquake science or the best earthquake science. We have also found that there is confusion about the national seismic hazard maps and that use of the maps may not result in sound public policy or engineering design in the central United States.

Following are our comments:

1. **PSHA – the methodology used for the national seismic hazard mapping – is not compatible with modern earthquake science**. PSHA has been used for the national seismic hazard mapping since the late 1970’s (Algermissen and Perkins, 1976; Algermissen and others, 1990; Frankel and others, 1996, 2002). PSHA was developed in the early 1970’s (Cornell, 1968, 1971) and become the most used method in seismic hazard assessment. Recent studies (Anderson and Brune, 1999; Wang and others, 2003, 2005; Wang, 2005, 2006; Wang and Ormsbee, 2005) showed that there are some intrinsic problems in PSHA. In a recent paper, Bommer and Abrahamson (2006) provided an excellent review of PSHA and its key issue: how the ground-motion uncertainty is treated. Although Bommer and Abrahamson (2006) recognized the dependency of ground-motion uncertainty on the source-to-site distance that is used to characterize a finite source, they failed to recognize the implication of this dependency to the formulation of PSHA. Wang and Zhou (in press) showed that the formulation of PSHA (hazard calculation) is mathematically invalid because of the dependency of ground-motion uncertainty on magnitude and distance. In other words, calculated hazard from PSHA does not have a clear physical meaning (NRC, 1988; Wang, 2005).

   In the early 1970’s, an earthquake was generally considered a point source, and epicentral or focal distance was modeled in the ground-motion attenuation relationship. The ground-motion uncertainty was not well understood and was treated as an independent random variable in the formulation of PSHA (Cornell, 1968, 1971). Today, however, an earthquake is considered a complex finite source, and the distance to the finite fault is modeled in the modern ground-motion attenuation relationship. The ground-motion uncertainty is an implicit or explicit dependence of earthquake magnitude and distance. As pointed out by Bommer and Abrahamson (2006), “this large variability (ground-motion uncertainty) is not due to the stations having significantly different site conditions but rather reflects the large variability of ground motions when the wave propagation from a finite fault is characterized only by the distance from the station to the closest point on the fault rupture.” In other words, PSHA is based on earthquake science from the 1970’s (point source, which is no longer valid), not on modern earthquake science (finite source).

2. **Clustered (time-dependent) model**. As stated in the document, the clustered model is time-dependent and considers occurrence of earthquakes as sequences. The fundamental assumption made in PSHA is time-independence of earthquake occurrences (Poisson model) (Cornell, 1968, 1971). In other words, the time-independent model is the basis for the national hazard mapping. This was discussed and concluded at the ATC-USGS users’ workshop on December 7-8, 2006, in San Mateo, Calif. The clustered model contradicts the basis of the national hazard mapping. How can this contradiction be reconciled?

   How much do we know about the occurrences of large earthquakes in the New Madrid Seismic Zone? Are there enough data to support a scientifically sound clustered model for the New Madrid zone? David Schwartz gave an excellent presentation on the earthquake cycle in the San Francisco Bay Area from 1600-2007, at IUGG-2007 in Perugia, Italy. He showed that the patterns of seismicity are different in different cycles. This suggests that there are not enough data to determine the cluster parameters of earthquake occurrences even in the San Francisco Bay area. There are not enough scientific data to support a sound clustered model for the New Madrid Seismic Zone even if the contradiction (time-independent versus time-dependent) can be reconciled.

3. **The input models (parameters) in the central United States may not reflect the best earthquake science**. As stated in the document, “the hazard models are revised using new ground shaking measures, geologic and seismologic studies of faults and seismicity, and geodetic strain data.” These may not be reflected in the selection of input models in the documentation, however. The reasons for selecting some key input models for the central United States, the New Madrid Seismic Zone in particular, are not well supported by "either published or thoroughly reviewed" publications and suggestions at numerous USGS hazard workshops.

   a. **New Madrid Faults.** Five “hypothetical” sub-parallel faults, instead of three “fictitious” sub-parallel faults (Frankel and others, 1996, 2002), were used in this update. As described in the document, “the central trace (fault) most closely follows the seismicity pattern.” In other words, the central fault is supported by thoroughly reviewed publications such as Johnston and Schweig (1996). The other traces (faults) are hypothetical and may not be supported by thoroughly reviewed publications. In particular, the northern arms (extension) of the New Madrid faults are arbitrary and not consistent with thoroughly reviewed publications, such as Johnston and Schweig (1996) and Baldwin and others (2005). The New Madrid faults of Johnston and Schweig (1996) were suggested for the national seismic hazard maps at the USGS hazard maps workshop in Boston, Mass., May 9-10, 2006.

b. **Recurrence interval of the New Madrid Seismic Zone.** Only the paleoliquefaction study (Tuttle and Schweig, 2004) is cited in the document and was used to determine the recurrence interval, 500 years, for large earthquakes in this zone. A recent study (Holbrook and others, 2006) indicates a recurrence interval of about 1,000 years for large earthquakes in the New Madrid Seismic Zone, however. The recurrence interval of 1,000 years is also consistent with geodetic strain data (Newman and others, 1999; Calais and others, 2006). These new studies were not considered, not even mentioned at all in the documentation. Geodetic strain data (GPS) provide new scientific information and were considered in the national seismic hazard mapping for the western United States. Many researchers from the central United States repeatedly asked the USGS to consider the geodetic data for the national seismic hazard maps at the ATC workshop on May 3, 2005, in Memphis, Tenn., the USGS hazard maps workshop May 9-10, 2006, in Boston, Mass., and the ATC-USGS users' workshop December 7-8, 2006, in San Mateo, Calif.

c. **Maximum magnitude for background seismicity.** Large background earthquakes were used in the national hazard mapping (Fig. 2 of the document) for the central and eastern United States. On a geologic time scale (millions of years), an M9.0 or larger earthquake could occur anywhere in the central United States because many places were either broken apart in the past or will be broken apart in the future. This great earthquake does not have any implication for seismic safety and policy, however, because it could occur in millions of years, a span much longer than human history, and in particular much longer than the time span for which a policy is being considered. The NBC movie, "10.5", in which California is broken apart, is good entertainment, but nobody worries about it because it may occur in millions of years or never. Without knowing its recurrence interval (how often), to consider a large background earthquake in the central and eastern United States is meaningless, particularly for the national seismic hazard mapping, which is intended for policy consideration. There is no contribution to the calculated hazards from the large background earthquakes. Use of the large background earthquakes in the central and eastern United States is unnecessary and causes confusion (Wang, 2002).

4. **There is confusion about the products of the U.S. national seismic hazard mapping project.** The documentation is the most important file for users. It should provide a clear description of products that are essential and useful for users. Any confusion about the products could cause problems.

    a. **The end products from the USGS national seismic hazard mapping project are a series of hazard curves (infinite points) at grid points across the Unite States.** The hazard curves describe a relationship between a ground-motion parameter (i.e., PGA, PSA, etc.) and its annual probability of exceedance or return period (reciprocal of annual probability of exceedance) in a range of ground motions (0 to 10g 0.2s PSA) and return periods (10 to 100,000 years) (Fig. 1). The ground motions with 500-, 1,000-, and 2,500-year return periods (equivalent to 10, 5, and 2 % PE in 50 years) (Fig. 1) are only three points on the hazard curves. The three maps (ground motions with 500-, 1,000-, and 2,500-year return periods) are just three out of an infinite number of possibilities. This should be made clear in the documentation. For policy consideration, the choices for users and policy-makers are not three, but infinite using the hazard curves of the United States national seismic hazard mapping.

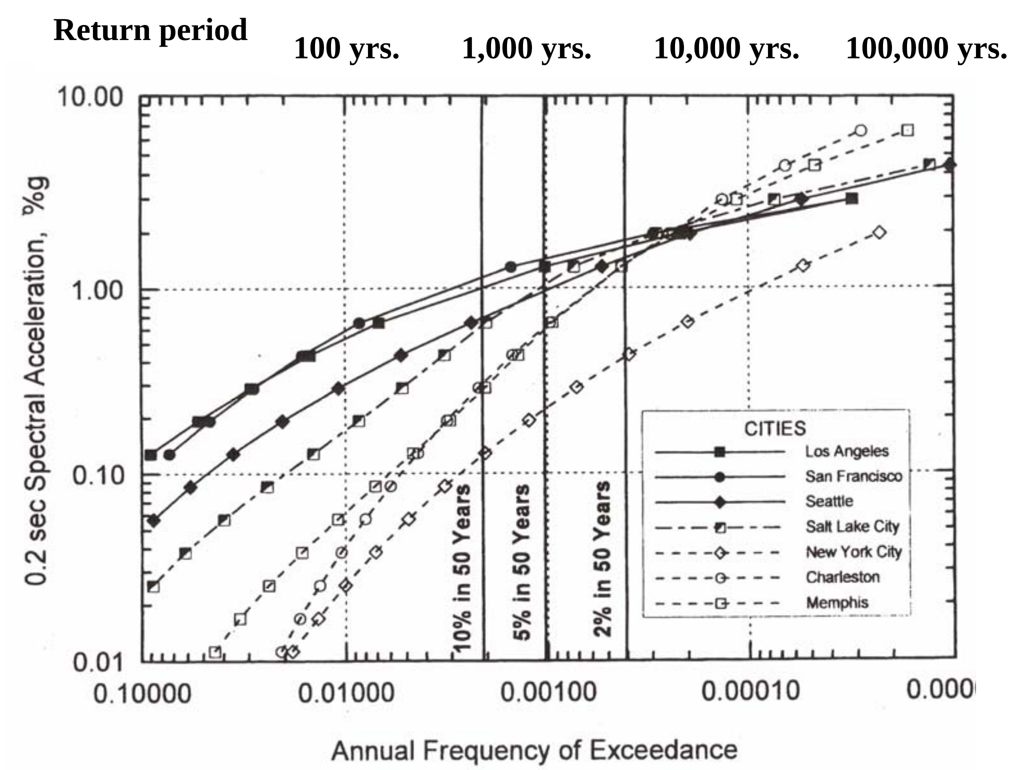

Figure 1. Hazard curves for selected cities (Leyendecker and others, 2000).

b. **Annual probability of exceedance or return period.** Annual probability of exceedance defined in PSHA is an extrapolation of earthquake recurrence intervals (temporal measure) and ground-motion uncertainty (spatial measure). But annual probability of exceedance is not a temporal measure and is not equal to “annual rate.” Therefore, return period (reciprocal of annual probability of exceedance) is not a temporal measure. The annual probability of exceedance is called “annual rate” in the documentation, however, and return period is treated as “the mean (average) time between occurrences of a certain ground motion at a site” (McGuire, 2004). This issue was brought up and discussed at the ATC-USGS users’ workshop December 7-8, 2006, in San Mateo, Calif. The participants at this workshop asked the USGS to clearly describe and communicate what the annual probability of exceedance or return period is.

c. **What is 10, 5, or 2% PE in 50 years?** By definition, 10, 5, and 2% PE in 50 years are risks in concept, and are calculated from return periods of about 500, 1,000, and 2,500 years (τ) and average building life of 50 years (t) according to

$$PE = 1 - e^{-t/\tau} \quad . \tag{1}$$

Equation (1) has been commonly used to calculate risk in term of X% PE in Y years for earthquakes, floods, wind, and other natural hazards based on Poisson occurrence of events (earthquakes, floods, wind, and others). For example, 1% PE in one year is the commonly used risk level in building design for flood hazard, and 2% PE in one year is used for wind hazard. From equation (1), the average occurrence interval of the flood corresponding to the 1% PE in one year is 100 years (100-year-flood), and the average occurrence interval of the 3-s gust-wind corresponding to the 2% PE in one year is 50 years. Return periods of 500, 1,000, and 2,500 years have been used as a temporal measure in the national hazard maps. This may not be appropriate, because the return period defined in PSHA is not a temporal measure and cannot be compared to the average occurrence intervals for floods, wind, and other natural hazards (Harris, personal communication). This point was brought up and discussed at the ATC-USGS users’ workshop December 7-8, 2006, in San Mateo, Calif. (Harris, 2006). Use of 10, 5, and 2% PE in 50 years is not only inappropriate for the national hazard maps, but also confusing and perhaps misleading.

In the New Madrid Seismic Zone, there is about 10% PE that a large earthquake (similar to the 1811-1812 events of about M7.5) could occur in the next 50 years (http://eqint.cr.usgs.gov/eq-men/html/neweqprob-06.html). But, the ground motions with 10%, 5%, 2% PE in 50 years have been produced from the same earthquake. It does not make scientific sense that there is about 10% PE of an M7.5 earthquake in the next 50 years, while ground motions that could be generated by the same earthquake at a site have 5, 4, 3, 2, and other percent PE in 50 years. Occurrence of an earthquake and occurrence of ground motion generated by the earthquake at a site must be the same (fundamental earthquake science).

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